

SEMICONDUCTOR DEVICES AND METHODS OF FORMING THE SAME

Cross Reference To Related Applications

This application claims priority under 35 U.S.C. § 119 to Korean Patent Application No. 2003-14387, filed March 7, 2003, the contents of which are incorporated herein in its entirety by reference.

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Field of the Invention

The present invention relates to semiconductor devices and methods of forming the same. More specifically, the present invention is directed to a semiconductor device having gate electrodes and methods of forming the same.

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Background of the Invention

Metal-oxide semiconductor (MOS) transistors include a gate electrode formed on a semiconductor substrate and a source/drain region formed in the semiconductor substrate adjacent to opposite sides of the gate electrode. The linewidth of the gate electrode may be an important dimension in the design of the device. As the size of 15 MOS transistors has decreased, a corresponding reduction in the linewidth of the gate electrode has also occurred. As the linewidth of the gate electrode is reduced, the resistance of the gate electrode typically increases. This increased resistance may reduce the operation speed of the MOS transistor, making it difficult to achieve high speed devices.

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A method of forming a gate electrode made of polycide has been proposed as a way to reduce the resistance of the gate electrode. The polycide layer has a structure in which a low-resistance metal silicide layer is stacked on a doped polysilicon layer. A MOS transistor having a conventional polycide gate electrode is illustrated in **FIG. 1**, and a cross-sectional view of the device taken along the line I-I' 25 of **FIG. 1** is shown in **FIG. 2**.

As shown in **FIGS. 1 and 2**, a device isolation layer **2** is provided on predetermined regions of a semiconductor substrate **1** to define a plurality of active regions **3**. A gate line **7** crosses over the active regions **3**. The gate line **7** includes a gate insulating layer **4**, a doped polysilicon layer **5**, and a metal silicide layer **6** which are stacked on the semiconductor substrate **1** in the order named. The metal silicide layer **6** may be made of cobalt silicide. The doped polysilicon layer **5** and the metal silicide layer **6** together form the gate electrode of the MOS transistor. An impurity diffusion layer **8** is provided on the active regions **3** adjacent opposite sides of the gate line **7**. The impurity diffusion layer **8** corresponds to the source/drain regions of the MOS transistor.

Since the metal silicide layer **6** has a lower resistance than the doped polysilicon layer **5**, the metal silicide layer **6** acts to reduce the resistance of the gate electrode. As semiconductor devices have become more highly integrated, the linewidth of the gate line **7** has been reduced. As the linewidths are reduced, defects may appear in the metal silicide layer **6** that can result in a crack in the metal silicide layer **6** (the crack is denoted as "A" in **FIGS. 1 and 2**). The crack **A** can negatively impact operation of the device, particularly in the case where the linewidth of the gate line **7** is similar to the grain size of the metal silicide layer **6**. Because of the crack **A** in the metal silicide layer **6**, the resistance of the gate electrode may be significantly increased. As a result, the operation speed of the MOS transistor may be reduced.

Summary of the Invention

Embodiments of the present invention provide semiconductor devices and methods of fabricating semiconductor devices that include a plurality of isolation regions in a semiconductor substrate that define an active region. A gate electrode that includes a metal silicide layer on a polysilicon layer is provided on the active region, and a conductive layer is electrically connected to the gate electrode. The conductive layer bridges at least one gap in the metal silicide layer. The conductive layer may be a conductive line pattern that is formed of aluminum, tungsten, titanium, tantalum, and/or copper. The conductive layer may decrease the resistance of the gate electrode. A gate insulation pattern may be provided between the active region and the gate electrode.

The semiconductor devices may further include an interlayer dielectric on the semiconductor substrate. The interlayer dielectric may have a groove in which the conductive line pattern is formed. The interlayer dielectric may include one or more

additional grooves in which plug lines are formed to electrically connect a source/drain region in the semiconductor device with a source/drain region of an adjacent semiconductor device.

In further embodiments of the present invention, the semiconductor device
5 may include a planarized interlayer dielectric on the semiconductor substrate. The top surface of this planarized interlayer dielectric and the top surface of the gate electrode may be at substantially the same height above the semiconductor substrate. The semiconductor device may also include a second active region in the semiconductor substrate with a second gate electrode thereon that includes a polysilicon layer. The
10 conductive layer in these devices may by a conductive line pattern that electrically connects the gate electrode and the second gate electrode.

According to further embodiments of the present invention, semiconductor devices are provided that include a semiconductor substrate and a gate line. The gate line includes a gate insulation pattern and a gate electrode which are sequentially stacked on the semiconductor substrate. A spacer is formed on a sidewall of the gate line, and a conductive line pattern is on the gate line. The conductive line pattern is parallel to the gate line and electrically connected to the gate electrode.
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In these semiconductor devices, the gate electrode may include a doped polysilicon layer, and may optionally also include a metal silicide layer on the doped
20 polysilicon layer. The semiconductor device may further include an interlayer dielectric on the semiconductor substrate, the gate line, and the spacer that includes a groove that exposes a top surface of the gate line. The conductive line pattern may be disposed in this groove. Alternatively, the semiconductor device may include an interlayer dielectric which is formed on the semiconductor substrate, gate line and
25 spacer that is planarized down to the top surface of the gate line. The length of the conductive line pattern may be at least as long as the length of the gate line. The conductive line pattern may be made of metal.

According to still further embodiments of the present invention,
semiconductor devices are provided that include first and second gate lines on a
30 semiconductor substrate. The first gate line includes a first gate insulation pattern and a first gate electrode which are stacked in the order named, and the second gate line includes a second gate insulation pattern and a second gate electrode which are stacked in the order named. A conductive line pattern may be provided on the first and second gate lines, and may have a first portion that is parallel to the first gate line

and a second portion that is parallel to the second gate line. The conductive line pattern may electrically connect the first and second gate electrodes with each other.

In these semiconductor devices, the first and second gate lines include a doped polysilicon layer, and may also include a metal silicide layer on the doped polysilicon layer. The device may also include a spacer on the sidewalls of the first and second gate lines. The first portion of the conductive line pattern may have at least the same length as the first gate line, and the second portion of the conductive line pattern may have at least the same length as the second gate line.

According to further embodiments of the present invention, a semiconductor device may be fabricated by forming a gate line that includes a gate insulation pattern and a gate electrode on a semiconductor substrate. A spacer is formed on a sidewall of the gate line, and an interlayer dielectric is formed on the semiconductor substrate, the spacer and the gate line. A top surface of the gate line is exposed, and a conductive line pattern is formed on the exposed gate line to be parallel with the gate line.

The gate electrode may include at least a doped polysilicon layer. The gate electrode may further include a metal silicide layer on the doped polysilicon layer. The top surface of the gate line may be exposed by patterning the interlayer dielectric to form a groove that exposes the top surface of the gate line. The conductive line pattern may be formed by forming a conductive layer on the surface of the semiconductor substrate to fill the groove and planarizing the conductive layer down to a top surface of the interlayer dielectric to form the conductive line pattern in the groove. Alternatively, the top surface of the gate line may be exposed by planarizing the interlayer dielectric until the top surface of the gate line is exposed. The conductive line pattern in such embodiments may then be formed by forming a conductive layer on the surface of a semiconductor substrate and the exposed the gate line and patterning the conductive layer to form the conductive line pattern on the gate line.

Pursuant to still further embodiments of the present invention, semiconductor devices are fabricated by forming a first gate line and a second gate line that is spaced apart from the first gate line on a semiconductor substrate. The first gate line includes a first gate line insulation pattern and a first gate electrode which are stacked in the order named, and the second gate line includes a second gate line insulation pattern and a second gate electrode which are stacked in the order named. A spacer is formed

on a sidewall of the first and second gate lines. An interlayer dielectric is formed on the surface of the semiconductor substrate including the spacer. Top surfaces of the first and second gate lines are exposed. A conductive line pattern is formed on the exposed first and second gate lines. The conductive line pattern has a portion parallel with the first gate line and a portion parallel with the second gate line and electrically connects the first and second gate electrodes with each other.

Brief Description of the Drawings

FIG. 1 is a top plan view of a conventional MOS transistor having a polycide gate electrode.

FIG. 2 is a cross-sectional view taken along a line I-I' of FIG. 2.

FIG. 3 is a top plan view of a semiconductor device having a gate electrode according to embodiments of the present invention.

FIG. 4 is a cross-sectional view of the device of FIG. 3 taken along the line II-II' of FIG. 3.

FIG. 5 is a cross-sectional view of the device of FIG. 3 taken along the line III-III' of FIG. 3.

FIGS. 6 and 7 are cross-sectional views of the device of FIG. 3 taken along the line III-III' of FIG. 3 during different stages of fabrication.

FIG. 8 is a perspective view of a semiconductor device according to further embodiments of the present invention.

FIGS. 9 and. 10 are cross-sectional views of the device of FIG. 8.

FIG. 11 is a top plan view of a semiconductor device according to further embodiments of the present invention.

FIG. 12 is a cross-sectional view of the device of FIG. 11 taken along the line IV-IV' of FIG. 11.

FIG. 13 is a cross-sectional view of the device of FIG. 11 taken along the line V-V' of FIG. 11.

FIG. 14 is a top plan view of an alternative conductive line pattern for semiconductor devices according to further embodiments of the present invention.

FIGS. 15A and 16A are cross-sectional views of the device of FIG. 11 taken along the line IV-IV' of FIG. 11 during different stages of fabrication.

FIGS. 15B and 16B are cross-sectional views of the device of FIG. 11 taken along the line V-V' of FIG. 11 during different stages of fabrication.

FIG. 17 is a cross-sectional view of a semiconductor device according to further embodiments of the present invention.

FIGS. 18 and 19 are cross-sectional views of the device of **FIG. 17** during different stages of fabrication.

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Detailed Description

The present invention will now be described more fully with reference to the accompanying drawings, in which embodiments of the invention are shown. This invention, however, may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments 10 are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the drawings, the thickness of layers and regions may be exaggerated for clarity. It will also be understood that when a layer or element is referred to as being "on" another layer, element or substrate, it can be directly on the other layer, element or substrate, or 15 intervening layers and/or elements may also be present. In contrast, when a layer/element is referred to as being "directly on" another layer/element, there are no intervening layers or elements present. Likewise, when an element is described as being "between" two other elements it may be the only element between the two other elements or additional elements may also be present. Like reference numerals refer to 20 like elements throughout.

An exemplary semiconductor device according to certain embodiments of the present invention will now be described with reference to **FIGS. 3, 4 and 5**. **FIG. 4** is a cross-sectional view taken along the line II-II' of **FIG. 3**, and **FIG. 5** is a cross-sectional view taken along the line III-III' of **FIG. 3**.

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Referring to **FIGS. 3, 4 and 5**, a device isolation layer **102** is provided on predetermined regions of a semiconductor substrate **10** to define at least one active region **103**. The device isolation layer **102** may, for example, be a trench isolation layer. A gate line **108** crosses over the active region **103**. The gate line **108** includes a gate insulation pattern **104** and a gate electrode **107** which are stacked on the 30 semiconductor substrate **10** in the order named. The gate insulation pattern **104** may, for example, be made of thermal oxide, and the gate electrode **107** may, for example, be made of doped polysilicon **105**. Alternatively, the gate electrode **107** may be made of a polycide that is composed of doped polysilicon **105** and metal silicide **106**. The

metal silicide **106** may, for example, be tungsten silicide, cobalt silicide, nickel silicide and/or titanium silicide.

- A spacer **110** is provided on a sidewall of the gate line **108**. The spacer **110** may be made, for example, of silicon oxide, silicon nitride, and/or silicon oxynitride.
- 5 An impurity diffusion layer **111** is provided in the semiconductor substrate **10** at the active region **103** adjacent to opposite sides of the gate line **108**. The impurity diffusion layer **111** corresponds to the source/drain region of the MOS transistor. The impurity diffusion layer **111** may include a lightly doped impurity diffusion layer **109a** and a heavily doped impurity diffusion layer **109b**.
- 10 An etch-stop layer **114** and an interlayer dielectric **115** are sequentially stacked on the device isolation layer **102**, the active region **103**, the gate line **108**, and the spacer **110**. The etch-stop layer **114** may be formed of an insulator having an etch selectivity with respect to the interlayer dielectric **115**. For example, if the interlayer dielectric **115** is made of silicon oxide, the etch-stop layer **114** may be formed of silicon nitride. The etch-stop layer **114** may also be omitted.
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A groove **117** in the interlayer dielectric **115** and the etch stop layer **114** exposes the top surface of the gate line **108**. A conductive line pattern **120a** is disposed in the groove **117**. The conductive line pattern **120a** is parallel to the gate line **108** and is electrically connected to the gate electrode **107**. The conductive line pattern **120a** may be at least the same length as the gate line **108**, and may be formed of a metal such as, for example, aluminum (Al), tungsten (W), titanium (Ti), tantalum (Ta) and/or copper (Cu). If the conductive line pattern **120a** is made, for example, of W, Al or Cu, a conductive metal nitride layer that acts as a barrier layer may also be conformally stacked in the groove **117** with the tungsten (or aluminum or copper) layer. The conductive metal nitride layer may be omitted. Although in FIG. 3 the conductive line pattern **120a** has the same width "W" as the gate line **108**, the conductive line pattern may be wider than the gate line **108**.

In the semiconductor devices depicted in FIGS. 3, 4 and 5, even if a crack is created at the metal silicide layer **106**, the increase in the resistance of the gate electrode **107** that the crack may otherwise cause may be reduced or prevented due to the conductive line pattern **120a**, as the conductive line pattern **120a** is electrically connected to the top surface of the gate electrode **107** and thereby may act to reduce the resistance of the gate electrode **107**. If the gate electrode **107** is made only of a doped polysilicon layer **105**, the conductive line pattern **120a** will be electrically

connected to the doped polysilicon layer **105**, which also may act to reduce the resistance of the gate electrode **107**. As the resistance of the gate electrode **107** is reduced due to the conductive line pattern **120a**, the operation speed of the MOS transistor may be enhanced.

5 As shown in **FIGS. 3 and 5**, a plug line **120b** may be provided at opposite sides of the conductive line pattern **120a**. The plug line **120b** is provided in a plug groove **118** which penetrates the interlayer dielectric **115** and the etch-stop layer **114** to expose a predetermined region of the impurity diffusion layer **111**. The plug line **120b** electrically connects adjacent impurity diffusion layers **111** with each other, and
10 may be parallel to the conductive line pattern **120a**. The plug line **120b** may be provided on both sides or just one side of the gate line **108**, or may be omitted altogether. The plug line **120b** may, for example, be made of the same material as the conductive line pattern **120a**.

15 A method of forming semiconductor devices according to certain embodiments of the present invention will now be described with reference to **FIGS. 6 and 7**.

20 As shown in **FIG. 6**, a device isolation layer **102** is formed in a semiconductor substrate **101** to define at least one active region. The device isolation layer **102** may be a trench isolation layer. A gate line **108** is formed on, and crossing over, the active region. The gate line **108** includes a gate insulation pattern **104** and a gate electrode **107** which are stacked on the active region in the semiconductor substrate **101** in the order named. The gate insulation pattern **104** may, for example, be made of thermal oxide, and the gate electrode **107** may be doped polysilicon **105**. Alternatively, the gate electrode **107** may be made of polycide that is composed of doped polysilicon **105** and metal silicide **106** which are stacked in the order named. The metal silicide **106** may, for example, be tungsten silicide, titanium silicide, cobalt silicide and/or nickel silicide. Using the gate line **108** and the device isolation layer **102** as a mask, impurities may be implanted at a low dose to form a lightly doped impurity diffusion layer **109a** in the active region adjacent opposite sides of the gate line **108**. A spacer layer may then be formed on the surface of the semiconductor substrate **101** including the lightly doped impurity diffusion layer **109a**. Next, as shown in **FIG. 6**, the spacer layer may be anisotropically etched to form a spacer **110** on the sidewalls of the gate line **108**. Using the gate line **108**, the spacer **110**, and the device isolation layer **102** as a mask, impurities may be implanted to form a highly doped impurity diffusion layer
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109b adjacent each of the lightly doped impurity diffusion layers **109a**. The lightly and heavily doped impurity diffusion layers **109a** and **109b** constitute a lightly doped drain or "LDD" type impurity diffusion layer **111**. The spacer **110** may, for example, be made of silicon oxide, silicon nitride and/or silicon oxynitride.

5 An etch-stop layer **114** and an interlayer dielectric **115** may then be sequentially formed on the surface of the semiconductor substrate **101** including the impurity diffusion layer **111**. The etch-stop layer **114** may be an insulating layer having an etch selectivity with respect to the interlayer dielectric **115**. For example, if the interlayer dielectric **115** is made of silicon oxide, the etch-stop layer **114** may be 10 made of silicon nitride. The etch-stop layer **114** may also be omitted.

The interlayer dielectric **115** and the etch-stop layer **114** are successively patterned to form a groove **117** that exposes the top surface of the gate line **108** and to form a plug groove **118** that exposes predetermined regions of at least two impurity diffusion layers **111**. The groove **117** typically will be parallel with the gate line **108**, 15 and has at least the same length as the gate line **108**, although this need not be the case. As illustrated in FIG. 6, the groove **117** may have the same width as the gate line **108** such that the groove **117** exposes the top surface of the gate line **108** and a portion of the spacer **110** so as to secure a processing margin. During the formation 20 of the groove **117** and the plug groove **118**, the etch-stop layer **114** may act to prevent the top surface of the gate line **108** and a surface of the impurity diffusion layer **111** from being degraded by the etch process.

As shown in FIG. 7, a conductive layer **120** is formed on the semiconductor substrate **101**. The conductive layer **120** fills the groove **117** and the plug groove **118**. The conductive layer may be made of metal such as, for example, tungsten, 25 aluminum, titanium, tantalum and/or copper. The conductive layer **120** also may include a barrier layer that is made of metal nitride, with the metal layer on the metal nitride layer.

The conductive layer **120** may then be planarized down to the top surface of the interlayer dielectric **115** to form a conductive line pattern **120a** in the groove **117** 30 and to form a plug line **120b** in the plug groove **118**, as shown in FIG. 5.

A semiconductor device according to further embodiments of the present invention will now be described with reference to FIG. 8. As the device is similar in certain respects to the semiconductor device described above with reference to FIGS. 3-7, the same numerals will be used below to denote like elements.

As shown in **FIG. 8**, a device isolation layer **102** is provided on predetermined regions of a semiconductor substrate **101** to define at least one active region in the semiconductor substrate **101**. A gate line **108** crosses over the active region. The gate line **108** includes a gate insulation pattern **104** and a gate electrode **107** which are stacked on the semiconductor substrate **101** in the order named. The gate electrode **107** may be made of doped polysilicon **105** and/or polycide. The polycide may be composed of polysilicon **105** and metal silicide **106** which are stacked in the order named.

A spacer **110** is provided on a sidewall of the gate line **108**. An impurity diffusion layer **111** is provided in the semiconductor substrate adjacent to opposite sides of the gate line **108**. A planarized interlayer dielectric **115a** is provided on the semiconductor substrate **101**, the gate line **108**, the spacer **110** and the device isolation layer **102**. The planarized interlayer dielectric **115a** may be a layer that is planarized until the top surface of the gate line **108** is exposed. A conductive line pattern **120a** is provided on the exposed gate line **108**. The conductive line pattern **120a** may be parallel to the gate line **108** and is electrically connected to the gate electrode **107**. In certain embodiments, the conductive line pattern **120a** is made of metal. If a crack forms in the metal silicide layer **106**, the tendency for the resistance of the gate electrode **108** to increase may be reduced or eliminated due to the conductive line pattern **120a**.

Methods of forming semiconductor devices according to further embodiments of the present invention will now be described with reference to **FIGS. 9 and 10**.

Referring to **FIGS. 9 and 10**, a gate line **108**, a spacer **110**, and an impurity diffusion layer **111** may be formed in the manner described above with reference to **FIG. 6**. An interlayer dielectric **115** may then be formed on the surface of the semiconductor substrate **101** including the gate line **108**, the spacer **110**, and the impurity diffusion layer **111**. The interlayer dielectric **115** may be made, for example, of silicon oxide.

The interlayer dielectric **115** may then be planarized, until the top surface of the gate line **108** is exposed, to form a planarized interlayer dielectric **115a**. A conductive layer **120** is then formed on the surface of a semiconductor substrate **101** including the exposed gate line **108**. The conductive layer **120** is patterned to form the conductive line pattern **120a** shown in **FIG. 8**.

The various layers of the semiconductor device depicted in FIGS. 8-10 may be formed using the materials described above for corresponding elements in the description of the semiconductor device depicted in FIGS. 3-7.

Semiconductor devices according to additional embodiments of the present invention will now be described with reference to FIGS. 11, 12 and 13. FIG. 12 is a cross-sectional view taken along line IV-IV' of FIG. 11 and FIG. 13 is a cross-sectional view taken long line V-V' of FIG. 11.

Referring to FIGS. 11, 12 and 13, a device isolation layer 202 is formed on predetermined regions of a semiconductor substrate 201 to define at least one first active region 203a and at least one second active region 203b.

A first gate line 208a is formed on, and crossing over, the first active region 203a, and a second gate line 208b is formed on, and crossing over, the second active region 203b. The first and second gate lines 208a and 208b are spaced apart from each other and may be co-linearly disposed. The first gate line 208a includes a first gate insulation pattern 204a and a first gate electrode 207a which are stacked in the order named. The second gate line 208b includes a second insulation pattern 204b and a second gate electrode 207b which are stacked in the order named. The first and second gate insulation patterns 204a and 204b may be made, for example, of thermal oxide. The first electrode 207a may include a first doped polysilicon 205a and/or a first polycide that is composed of the first doped polysilicon layer 205a and a first metal silicide layer 206a which are stacked in the order named. The second gate electrode 207b may include a second doped polysilicon layer 205b and/or a second polycide that is composed of the second doped polysilicon layer 205b and a second metal silicide 206b. The first and second doped polysilicon layers 205a and 205b may be doped with the same or different conductive impurities. The first and second metal silicides 206a and 206b may be formed, for example, of tungsten silicide, cobalt silicide, nickel silicide and/or titanium silicide.

A first impurity diffusion layer 211a is formed in the semiconductor substrate 201 adjacent opposite sides of the first gate line 208a. A second impurity diffusion layer 211b is formed in the semiconductor substrate 201 adjacent to opposite sides of the second gate line 208b. The first and second impurity diffusion layers 211a and 211b may be doped with the same or different conductive impurities. A spacer 210 is provided on sidewalls of the first and second gate lines 208a and 208b. The spacer

210 may be formed, for example, of silicon oxide, silicon nitride and/or silicon oxynitride.

An etch-stop layer **214** and an interlayer dielectric **215** may then be sequentially stacked on the surface of the semiconductor substrate **201**, including the 5 first and second gate lines **208a** and **208b**. The etch-stop layer **214** may be formed of an insulation material having an etch selectivity with respect to the interlayer dielectric **215**. For example, if the interlayer dielectric **215** is formed of silicon oxide, the etch-stop layer **214** may be formed of silicon nitride. The etch-stop layer **214** may be omitted.

10 As shown best in FIG. 13, a groove **217** may be formed in the interlayer dielectric **215** and the etch-stop layer **214** to expose the top surfaces of the first and second gate lines **208a** and **208b**. A conductive line pattern **220a** is formed in the groove **217**. The conductive line pattern **220a** includes a portion that is parallel with the first gate line **208a**, a portion that is parallel with the second gate line **208b**, and a 15 connecting portion. The portion of the conductive line pattern **220a** that is parallel with the first gate line **208a** may be at least the same length as the first gate line **208a**, and the portion that is parallel with the second gate line **208b** may be at least the same length as the second gate line **208b**. The conductive line pattern **220a** electrically connects the first and second gate electrodes **207a** and **207b** with each other. The 20 conductive line pattern **220a** may be formed of metal such as, for example, aluminum, tungsten, titanium, tantalum and/or copper. The conductive line pattern **220a** may further include a metal nitride barrier layer that is interposed between the first and second gate electrodes **207a** and **207b** and the metal layer of conductive line pattern **220a**.

25 The first gate line **208a** and the first impurity diffusion layers **211a** constitute a first MOS transistor, and the second gate line **208b** and the second impurity diffusion layers **211b** constitute a second MOS transistor. The first MOS transistor may be an NMOS transistor or a PMOS transistor. Similarly, the second MOS transistor may be an NMOS transistor or a PMOS transistor.

30 In the above-described semiconductor device, the conductive line pattern **220a** may reduce the resistance of the first and second gate electrodes **207a** and **207b** and electrically connect the first and second gate electrodes **207a** and **207b** with each other. As such, if a crack forms in one or both of the first and second metal silicide layers **206a** and **206b**, the impact of the crack(s) on the resistance of the first and/or

second gate electrodes **207a** and **207b** may be reduced. Moreover, even if the first and second metal silicide layers **206a** and **206b** are omitted, the conductive line pattern **220a** may reduce the resistance of the first and second gate electrodes **207a** and **207b**. The conductive line pattern **220a** also acts as an interconnection for
5 electrically connecting the first and second gate electrodes **207a** and **207b** with each other. Such an arrangement may reduce the interconnection resistance as compared to a typical interconnection structure using contact plugs with an interconnection disposed thereon. Thus, semiconductor devices according to certain embodiments of the present invention may reduce, minimize or prevent the resistance of the gate
10 electrode from increasing when a crack forms in the metal silicide layer. Further, the first and second gate electrodes **207a** and **207b** are directly connected to each other which may facilitate providing a high-speed semiconductor device.

15 **FIG. 14** illustrates a semiconductor device according to additional embodiments of the present invention in which the first and second gate lines **208a** and **208b** are disposed on different lines.

As shown in **FIG. 14**, the first and second gate lines **208a** and **208b** are formed to cross respective first and second active regions **203a** and **203b**, which are spaced apart from each other. The first and second gate lines **208a** and **208b** are spaced apart from each other and are perpendicular to each other viewed from a top plan view. A conductive line pattern **220a** is formed on the first and second gate lines **208a** and **208b**. A connecting portion "B" of the conductive line pattern **220a** may vertically bend according to the position of the first and second gate lines **208a** and **208b**.

25 Cross-sectional views taken along a line IV-IV' of **FIG. 11** are illustrated in **FIGS. 15A** and **16A**, and cross-sectional views taken along a line V-V' of **FIG. 11** are illustrated in **FIGS. 15B** and **16B**.

Referring to **FIGS. 15A** and **16A**, a device isolation layer **202** is formed in predetermined region of a semiconductor substrate **201** to define at least one first active region and at least one second active region. A first gate line **208a** is formed on, and crossing over, the first active region, and a second gate line **208b** is formed on, and crossing over, the second active region. The first and second gate lines **208a** and **208b** are spaced apart from each other. The first gate line **208a** includes a first gate insulation pattern **204a** and a first gate electrode **207a** which are stacked on the semiconductor substrate **201** in the order named. The second gate line **208b** includes

a second gate insulation pattern **204b** and a second gate electrode **207b** which are stacked on the semiconductor substrate **201** in the order named.

The first and second gate insulation patterns **204a** and **204b** may be formed, for example, of thermal oxide. The first gate electrode **207a** may include a first doped polysilicon layer **205a** or a first polycide. The first polycide may include a first doped polysilicon layer **205a** and a metal silicide **206a** which are stacked in the order named. The second gate electrode **207b** may include a second doped polysilicon layer **205b** and/or a second polycide. The second polycide may include a second doped polysilicon layer **205b** and/or a second metal silicide **206b**. The first and second doped polysilicon layers **205a** and **205b** may be doped with the same or different conductive impurities. The first and second metal silicide layers **206a** and **206b** may be formed of, for example, tungsten silicide, cobalt silicide, nickel silicide and/or titanium silicide.

Impurities are implanted into the semiconductor substrate **201** adjacent to opposite sides of the first gate line **208a** and into the semiconductor substrate **201** adjacent to opposite sides of the second gate line **208b** to form a first impurity diffusion layer **211a** and a second impurity diffusion layer **211b**, respectively. The first and second impurity diffusion layers **211a** and **211b** may be formed to have an LDD structure. The first and second impurity diffusion layers **211a** and **211b** may include the same or different conductive impurities, and may be formed simultaneously or sequentially. A spacer **210** may be formed on sidewalls of the first and second gate lines **208a** and **208b**. The spacer **210** may be formed, for example, of silicon oxide, silicon nitride and/or silicon oxynitride.

An etch-stop layer **214** and an interlayer dielectric **215** are sequentially formed on the surface of a semiconductor substrate **201** including the spacer **210**. The etch-stop layer **214** may be formed of an insulating material having an etch selectivity with respect to the interlayer dielectric **215**. For example, if the interlayer dielectric **215** is made of silicon oxide, the etch-stop layer **214** may be made of silicon nitride. The etch-stop layer **214** may be omitted.

The interlayer dielectric **215** and the etch-stop layer **214** are successively patterned to form a groove **217** that exposes the top surfaces of the first and second gate lines **208a** and **208b**. The etch-stop layer **214** may protect the top surfaces of the first and second gate lines **208a** and **208b** from damage when the groove **217** is

formed. In addition, the etch-stop layer may help to prevent overetching of the interlayer dielectric 215 between the first and second gate electrodes 207a and 207b.

Referring to FIGS. 16A and 16B, a conductive layer 220 is formed on the surface of the semiconductor substrate 201 to fill the groove 217. The conductive layer 220 may be formed of a metal such as, for example, tungsten, aluminum, titanium, tantalum and/or copper. In some cases, the conductive layer 220 may include a metal nitride barrier layer. The conductive layer 220 may then be planarized down to the top surface of the interlayer dielectric 215 to form the conductive line pattern 220a shown in FIGS. 12 and 13

A cross-sectional view of a semiconductor device according to the further embodiments of the present invention is illustrated in FIG. 17.

As shown in FIG. 17, the semiconductor device may include a device isolation layer 202, first and second gate lines 208a and 208b, a spacer 210, and first and second impurity diffusion layers 211a and 211b. These portions of the device are described previously herein with respect to FIGS. 11, 12 and 13.

A planarized interlayer dielectric 215a is formed on the semiconductor substrate 201, the device isolation layer 202, the first and second gate lines 208a and 208b, the spacer 210, and the first and second impurity diffusion layers 211a and 211b. The planarized interlayer dielectric 215a is a layer that is planarized until the top surfaces of the first and second gate lines 208a and 208b are exposed. A conductive line pattern 220a is disposed on the exposed first and second gate lines 208a and 208b. The conductive line pattern 220a has a portion that is parallel to the first gate line 208a and a portion that is parallel to the second gate line 208b. The portion parallel to the first gate line 208a of the conductive line pattern 220a may have at least the same length as the first gate line 208a. The portion parallel to the second gate line 208b of the conductive line pattern 220a may have at least the same length as the second gate line 208b.

The conductive line pattern 220a may be formed to cover the entire length of the top surfaces of the first and second gate lines 208a and 208b. The conductive line pattern 220a electrically connects the first and second gate electrodes 207a and 207b with each other. Thus, the conductive line pattern 220a may reduce the resistance of the first and second gate electrodes 207a and 207b and act to interconnect the first and second gate electrodes 207a and 207b. As a result, it is possible to reduce, minimize and/or prevent the resistance of the gate electrode from increasing if a crack

is formed in the metal silicide layer. Additionally, the spaced electrodes **207a** and **207b** are directly connected to each other, which may facilitate providing a high-speed semiconductor device.

A method of forming semiconductor devices according to further 5 embodiments of the present invention will now be described with reference to FIGS. **18** and **19**.

As shown in FIGS. **18** and **19**, first and second gate lines **208a** and **208b**, a spacer **210**, and first and second impurity diffusion layers are formed in the same manner as described above in the discussion of FIGS. **15A** and **15B**. An interlayer 10 dielectric **215** is formed on the surface of the semiconductor substrate **201**, including the first and second gate lines **208a** and **208b** and the spacer **210**.

The interlayer dielectric **215** is planarized, until the top surfaces of the first and second gate lines **208a** and **208b** are exposed to form a planarized interlayer dielectric **215a**. A conductive layer **220** is formed on the surface of a semiconductor 15 substrate, including the exposed first and second gate lines **208a** and **208b**. The conductive layer may be formed of metal. The conductive layer **220** is patterned to form the conductive line pattern **220a** that is shown in FIG. **17**.

In the third and fourth embodiments, corresponding elements may be made of the same materials.

20 While this invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined by the appended claims and equivalents.